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METHOD FOR MEASURING SONIC DISLOCATION VELOCITIES

BY

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Method for Measuring Sonic Dislocation Velocities

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INTRODUCTION

Knowledge of the velocities with which dislocations in crystalline materials move is valuable in many branches of the science of solids. Experimental data of this kind makes it possible to express macroscopic strain-rates in terms of individual dislocation motions and dislocation multiplication rates, thus forming a bridge between microscopic and macroscopic phenomena. A specific problem whose solution depends on this type of information is that of fracture in semi-brittle materials where dislocations move near a crack tip at a variety of velocities up to sonic ones.

The purpose of the present paper is to present a new technique for applying dynamic stresses to elastic-plastic specimens. Outstanding features of the method are its simplicity and the well defined state of stress that it produces. Intensity of the stress and the stress-rate can be varied over a larger range than most other methods allow. Although the method was developed for studying high-speed dislocation motions in crystals, it can readily be adapted to studies of macroscopic plastic flow.

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*Now at Royal Institute of Technology, Stockholm, Sweden

METHOD OF LOADING

The method is intended to be used with specimens in the form of bars or parts of systems of bars (e.g., a penny-shaped piece clamped between two bars of equal length). Dynamic stresses are produced by simultaneously setting off explosive charges at both ends of a bar. The elastic stress pulses produced by the two explosions meet at the center of the bar and reinforce each other. This doubles the stresses in a region equal to the pulse length. Precise reinforcement at a given location along a bar (say, at the penny shaped specimen mentioned above) requires simultaneity of the detonations within one-tenth microsecond.

Ignition technique

In order to achieve the above simultaneity requirement, fine exploding wires were used to trigger the detonations. In this way, a small part of the explosive material could be brought up to its ignition temperature within a small fraction of a microsecond. The wires were in contact with the explosives and were connected in parallel (Figure 1). They were exploded by discharging a capacitor into them through a spark-gap. This gap was ionized by means of a thyratron in order to obtain a fast discharge and closely control the time at which the detonations occurred.

The physics of the explosion of wires is essentially understood [1]. What happens is that application of the voltage to the wire causes a large current to flow which quickly melts the wire, and continued heating vaporizes it into a gas at high pressure. During these events the resistance increases until the current is completely suppressed (Figure 2-Point A). As the vapor expands, the pressure decreases below the breakdown value for the remaining voltage. Reignition occurs (Figure 2-Point B) and the capacitor discharges rapidly through the ionized gas. The period A-B is usually called the current dwell, and lasts 2-5 μsec. for metals like copper and Nichrome (Fig. 2a). However, there is no current dwell at all for tungsten (Fig. 2b), evidently because the vaporization temperature is close to the ionization temperature.

The three types of wires just mentioned were investigated as possible ignitors for explosives. Copper and Nichrome gave a delay between the two ignitions of up to several microseconds. For tungsten the ignitions occurred simultaneously within the accuracy of the method used for determination of the delay time; i.e., within $<\frac{1}{50}$ μsec.

The simultaneity of two ignitions was determined by filling a small hole in a Teflon rod with an explosive and causing ignition at both ends of the rod. The resulting deformation pattern inside the hole showed very accurately where the two shock waves from the ends met. From this, and the detonation velocity, the delay time between the two ignitions could be determined.

For the plastic deformation studies, tungsten wires 1 mil ($\sim$ 0.025 mm) in diameter were used at a voltage of 2000V. The two ignition wires were coupled in parallel. Attempts to put them in series were not successful because the first ignition usually blows away the conducting plasma, and thereby opens the circuit before enough energy has been discharged to ignite the second explosive.

Explosive

The explosive material was lead azide (PbN_6) in the form of fine powder. It has an ignition temperature of 380°C, which is readily and very quickly reached by the exploding wire. The normal ignition temperature may even not be significant in this case, since the evidence above suggests that explosion of the wire may be required for ignition. The smallest explosives used weighed 2 mg. and gave an impulse of $\sim 1 \times 10^{-3}$ kg-m/sec. when used on a bar of steel with a cross-section of 0.2 cm x 0.25 cm.

Strains were measured with short (0.3 cm) semiconductor strain-gages glued to the specimen with Hysol Epoxy cement. The lengths of the stress pulses 4-5 cm from the explosives were usually 0.3-0.4 cm for a bar with the cross section given above.

Fig. 3b shows the result of a strain measurement. The strain-gage was 0.3 cm long and oriented to measure the longitudinal strain. Fig. 3a shows the expected output from the gage for a square pulse of 0.5 cm length and with the same impulse as the actual pulse in Fig. 3b. Thus the observed pulse is quite consistent with expectations. Figure 3 also shows a reflected pulse which has become more distorted than the primary pulse.

STUDIES OF DISLOCATION MOTION

The method has been applied to studies of dislocation motion in crystals of lithium fluoride. The crystals were annealed so that the majority of the dislocations were locked. A fine longitudinal scratch was made along one side of each crystal. Immediately thereafter the crystal was stressed explosively as described above. Then the crystal was etched to reveal dislocation positions.

Dislocation motion caused by reinforcement of the two pulses at the middle of the crystalline rod is shown in Figs. 4 and 5. At higher stresses defects in the crystals acted as stress raisers and glide bands were nucleated at places other than at the scratch as seen in Fig. 5.

The observed behavior illustrates quite well the special characteristic of plastic deformation upon which the success of the method depends. This is that dislocation velocities increase exponentially with applied stress [2] . Therefore, doubling the stress increases the velocity by a factor of 10^4 in a certain range. Stress magnitudes were varied in these experiments in the following ways:

1) By varying the amount of the explosive. However, amounts smaller than the 2 mg. mentioned above are difficult to prepare and ignite.

2) By varying the cross-sectional size of the specimen.

3) By putting a bar of variable length between the crystal and explosive*.

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*This also changes the loading rate, which is a disadvantage unless the intention is to study the effect of different loading rates.

In the case of brittle crystals, short ductile bars must be glued to the ends of the crystals to prevent shattering of the ends by the detonations.

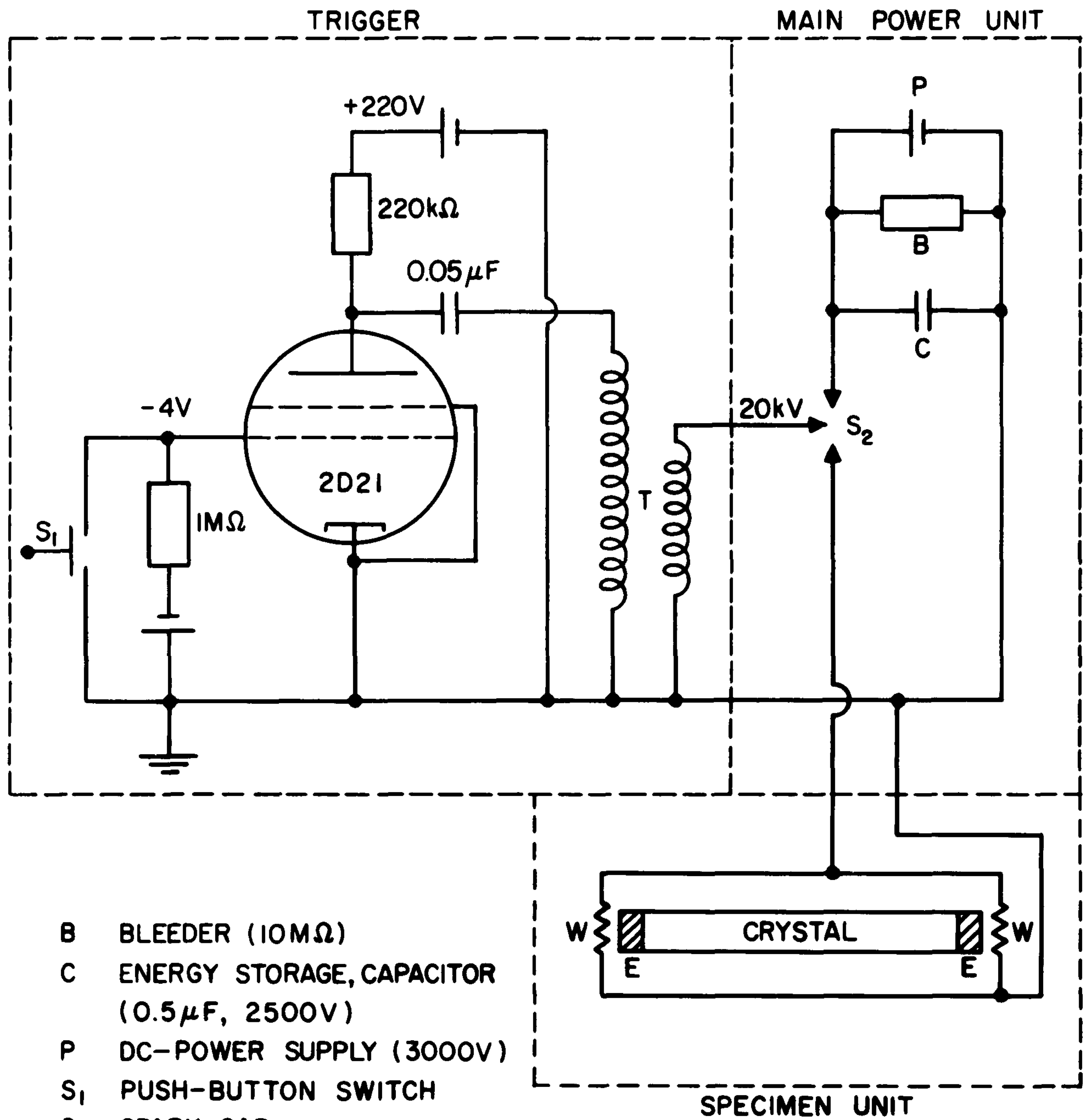
In order to measure dislocation or plastic wave fronts of the highest possible velocities, it is necessary to use the shortest possible stress pulses. Since the minimum pulse length is limited in bars by dispersion caused by the lateral inertia, this means that thin bars must be used. This becomes feasible with the method described here, and dislocation velocities as high as the dilational wave velocity can be measured, as may be seen in Figure 5.

CONCLUSIONS

The present method has some distinct advantages over other comparable methods used for studying dynamic plastic flow.

In studies of dislocation motion in mono-crystals the method gives a deformation pattern distinct enough to be seen even in crystals of relatively high dislocation density. This is valuable since high quality crystals sometimes cannot be obtained.

In studies of dynamic plasticity, specimens have usually been stressed with one pulse whose magnitude is above the yield stress. This gives a large amount of deformation at the point of loading where the stress state is complex and stress measurements are difficult. The present method allows one to obtain a high stress at any desired point along the length of a bar. The stresses are obtained by addition of well-defined elastic pulses and thus are simple to analyze. The state of stress is uniaxial in the region of reinforcement, and although only compressive loading is described here, the method can be adapted for producing tensile loads.



B BLEEDER (10MΩ)

C ENERGY STORAGE, CAPACITOR (0.5µF, 2500V)

P DC-POWER SUPPLY (3000V)

S_1 PUSH-BUTTON SWITCH

S_2 SPARK GAP

T PULSE TRANSFORMER (OUTPUT 20kv)

W TUNGSTEN WIRES (1 MIL DIAM.)

E EXPLOSIVE CHARGES (LEAD AZIDE)

FIG. 1 CIRCUIT USED FOR SIMULTANEOUS EXPLOSION OF TWO WIRES

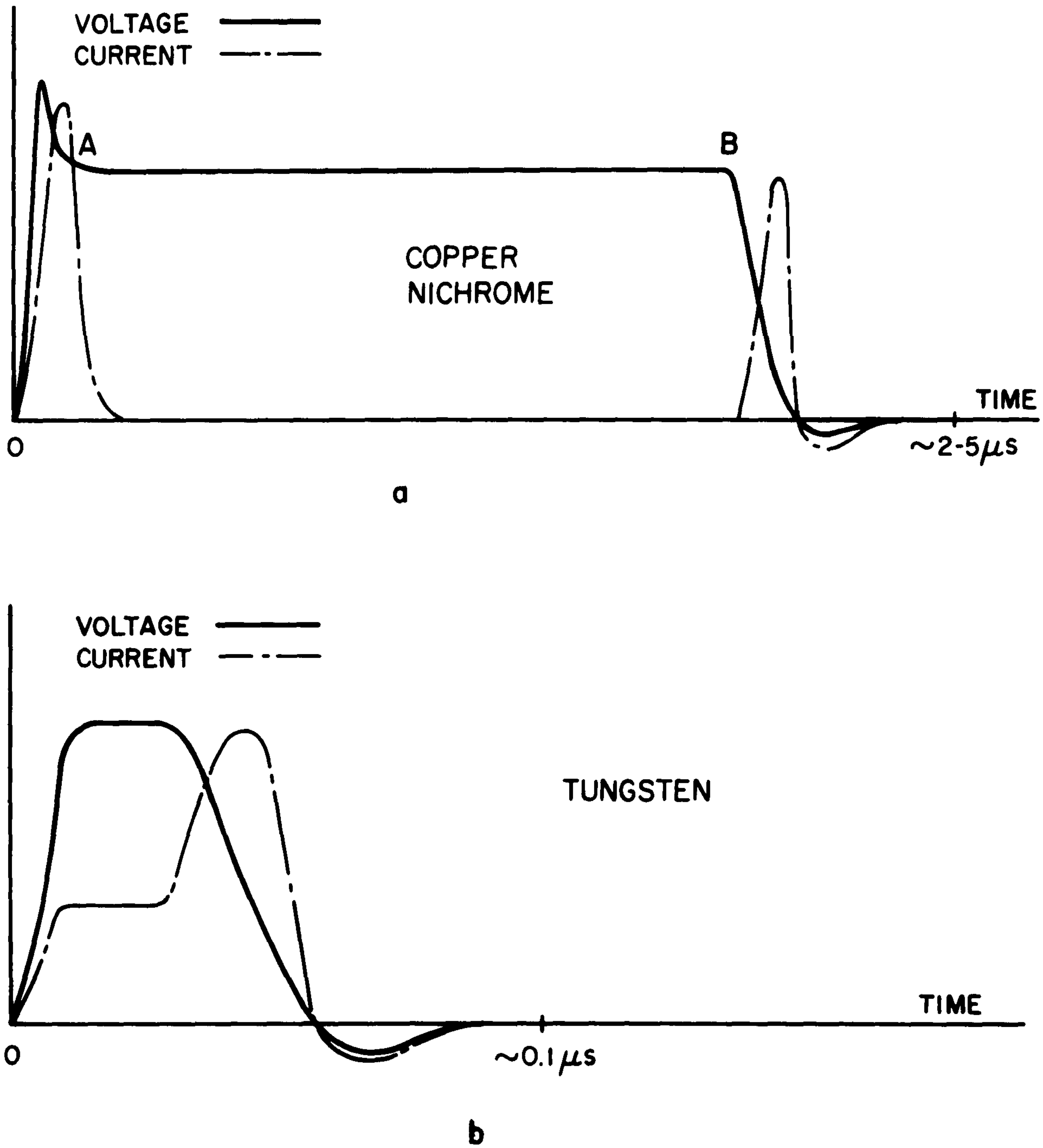
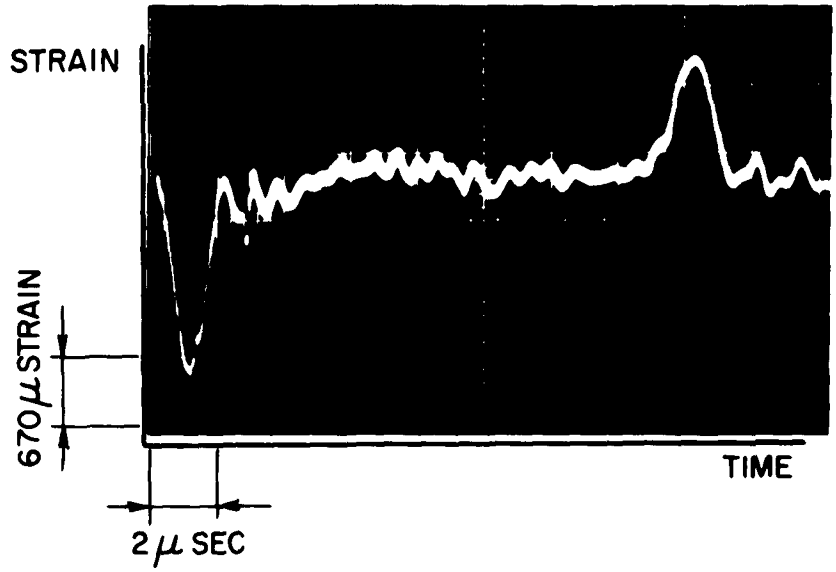
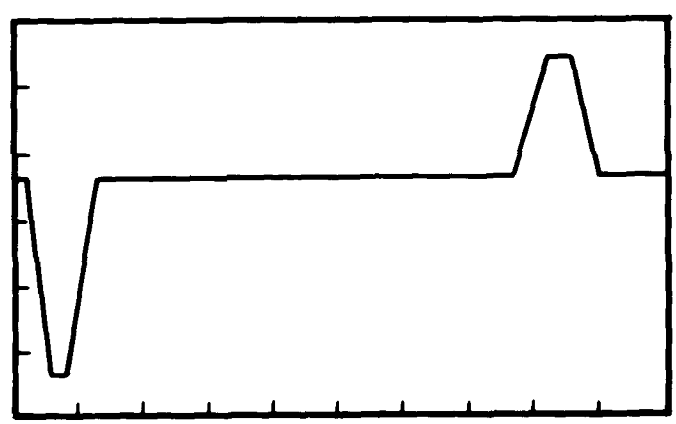


FIG. 2 SCHEMATIC CHARACTERISTICS OF EXPLODING WIRES
($\frac{1}{3}$ - 2 MIL., 1000 - 2500 VOLTS)



a



b

FIG. 3 (a) RESULT OF STRAIN MEASUREMENT ON STEEL SPECIMEN OF 0.2 cm. x 0.25cm. CROSS SECTION. STRAIN GAGE 0.3cm. LONG. MOUNTED LONGITUDINALLY.

(b) EXPECTED OUTPUT FOR SQUARE PULSE OF 0.5cm. LENGTH

FIG. 4. REGION IN THE MIDDLE OF A SPECIMEN WHERE THE STRESS PULSES REINFORCED EACH OTHER CAUSING LOCAL DISLOCATION MOTION.

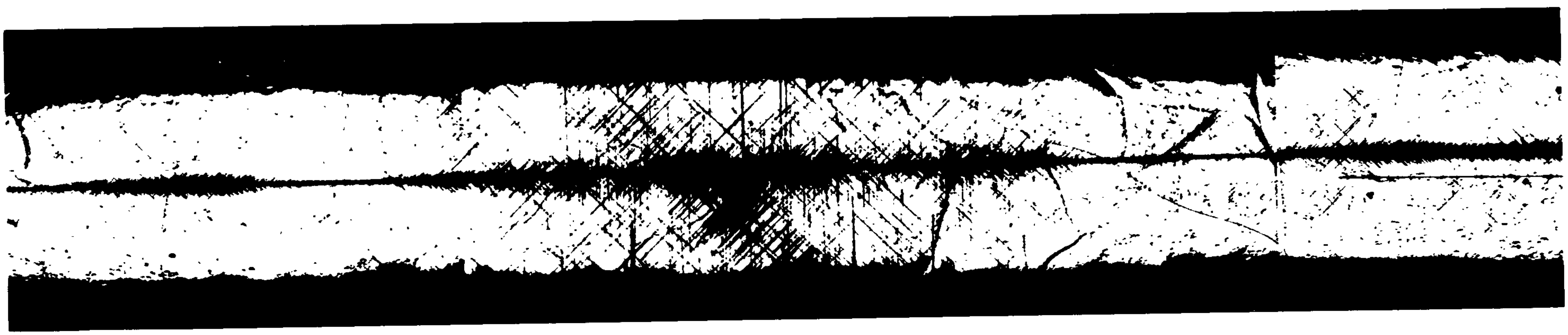


FIG. 5. WHOLE SPECIMEN AFTER LOADING AND ETCHING. STRENGTH OF PULSE HIGHER THAN IN FIG. 4. MAIN DEFORMATION AT CENTER PLUS TWO SATELLITES CAUSED BY INTERACTIONS BETWEEN EACH PRIMARY PULSE AND THE SLOWER SECONDARY PULSE FOLLOWING THE CONJUGATE PRIMARY PULSE.

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